

Searching for Long-Period X-ray Modulation in AXP 1E 2259+586

AXP 1E2259+586における 長周期X線変調の探索

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~中性子星の観測と理論~

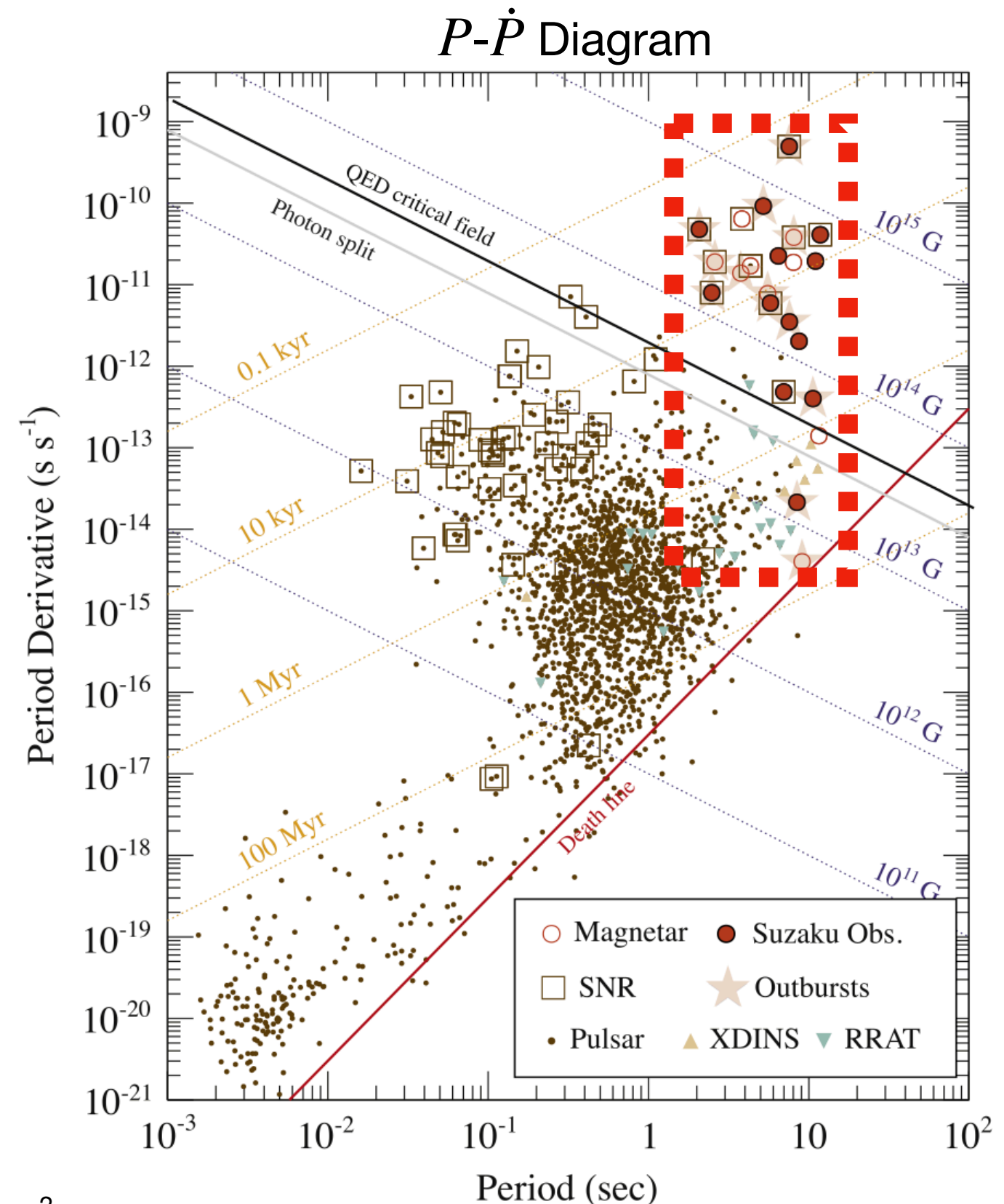
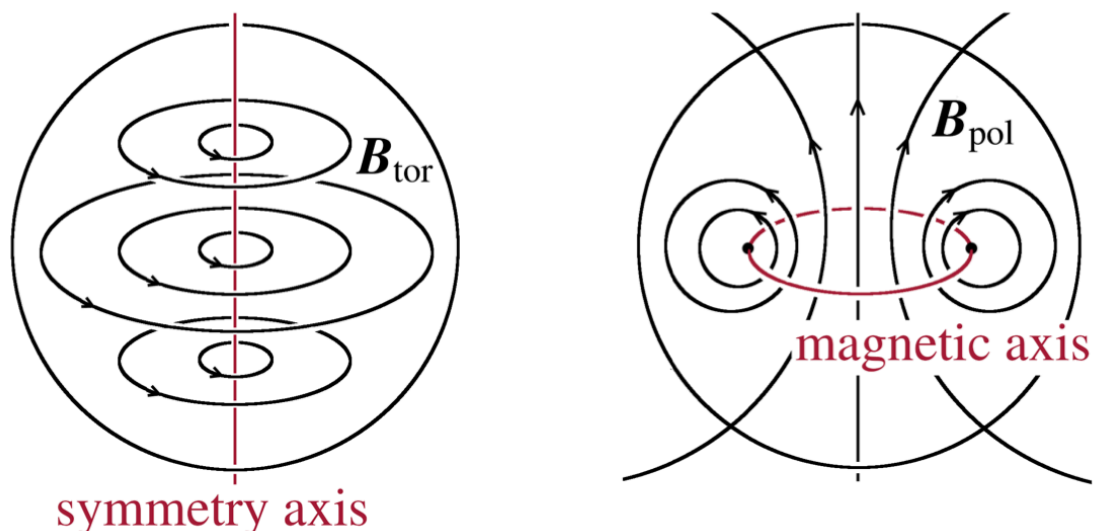
研究活性化ワークショップ2025

5/19-5/21 理化学研究所和光キャンパス

Magnetars (SGR/AXP)

Soft Gamma-ray Repeater Anomalous X-ray Pulsar

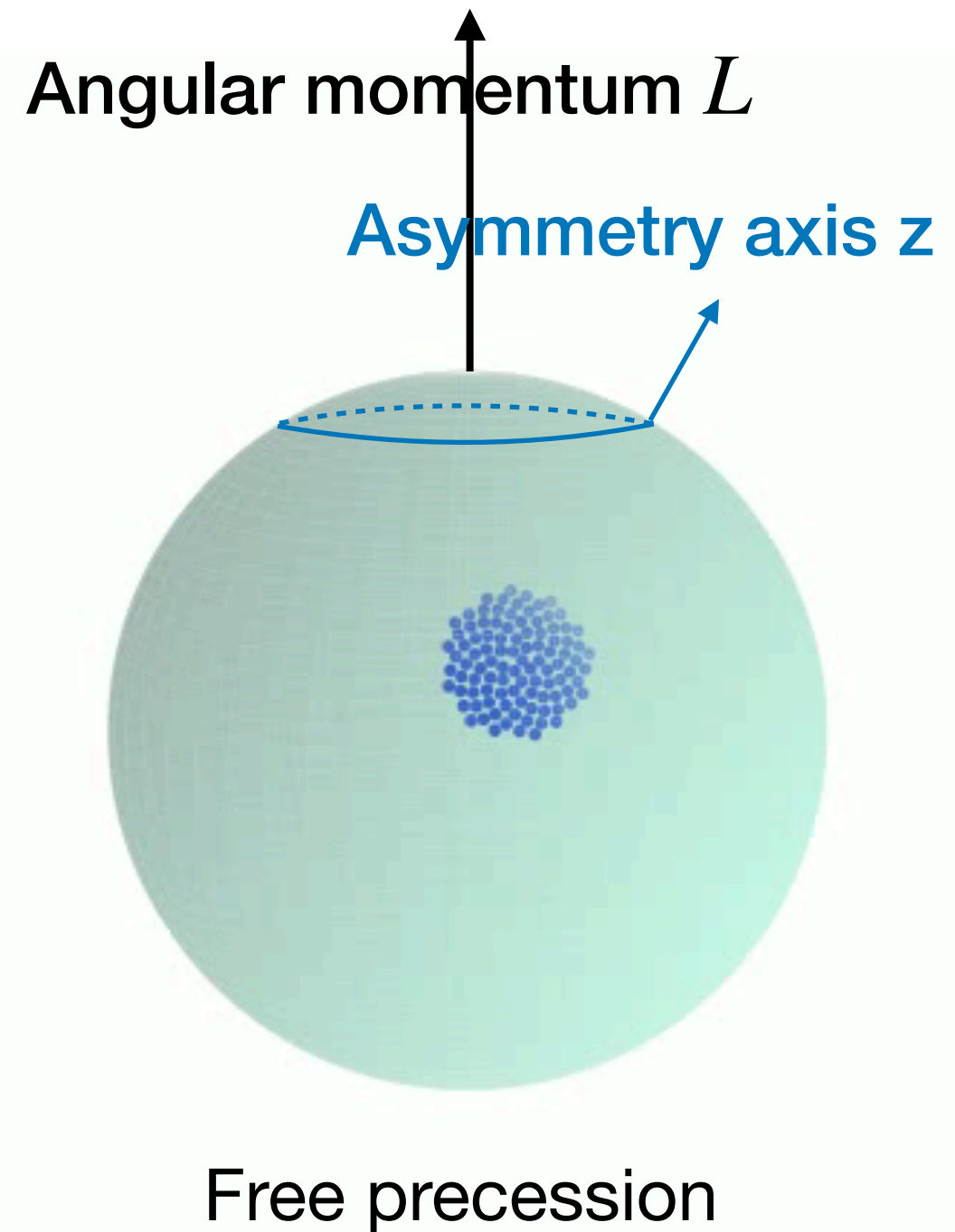
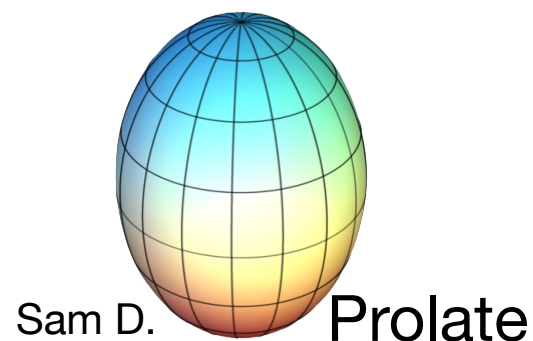
- $L_X \sim 10^{33} - 10^{35} \text{ erg/s} > \dot{E}_{rot}$
- Long period & Fast decay
 $P \sim 2 - 12 \text{ s}$
 $\dot{P} \sim 10^{-13} - 10^{-10} \text{ s/s}$
- Strong magnetic field
 $B_{surf} \sim 10^{14} \text{ G} - 10^{15} \text{ G}$
- 30+ detected (~ 1 per yr)



Magnetar free precession

- Inertial B pressure
- Prolate deformation
- Free precession

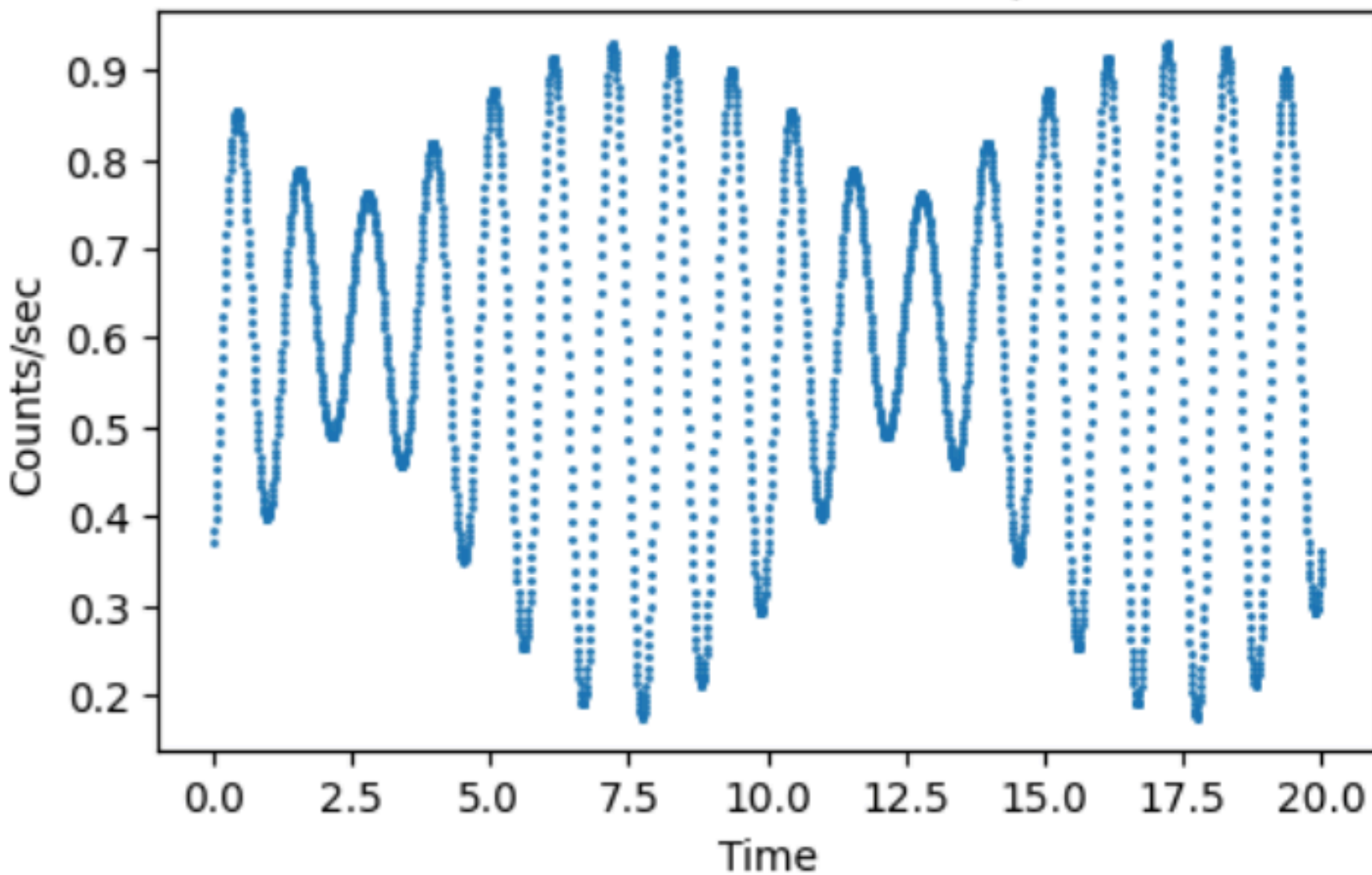
$$B_{tor} > B_{pol}$$



Magnetar free precession

• Inertial B pressure

mock data (consider motion of precession)



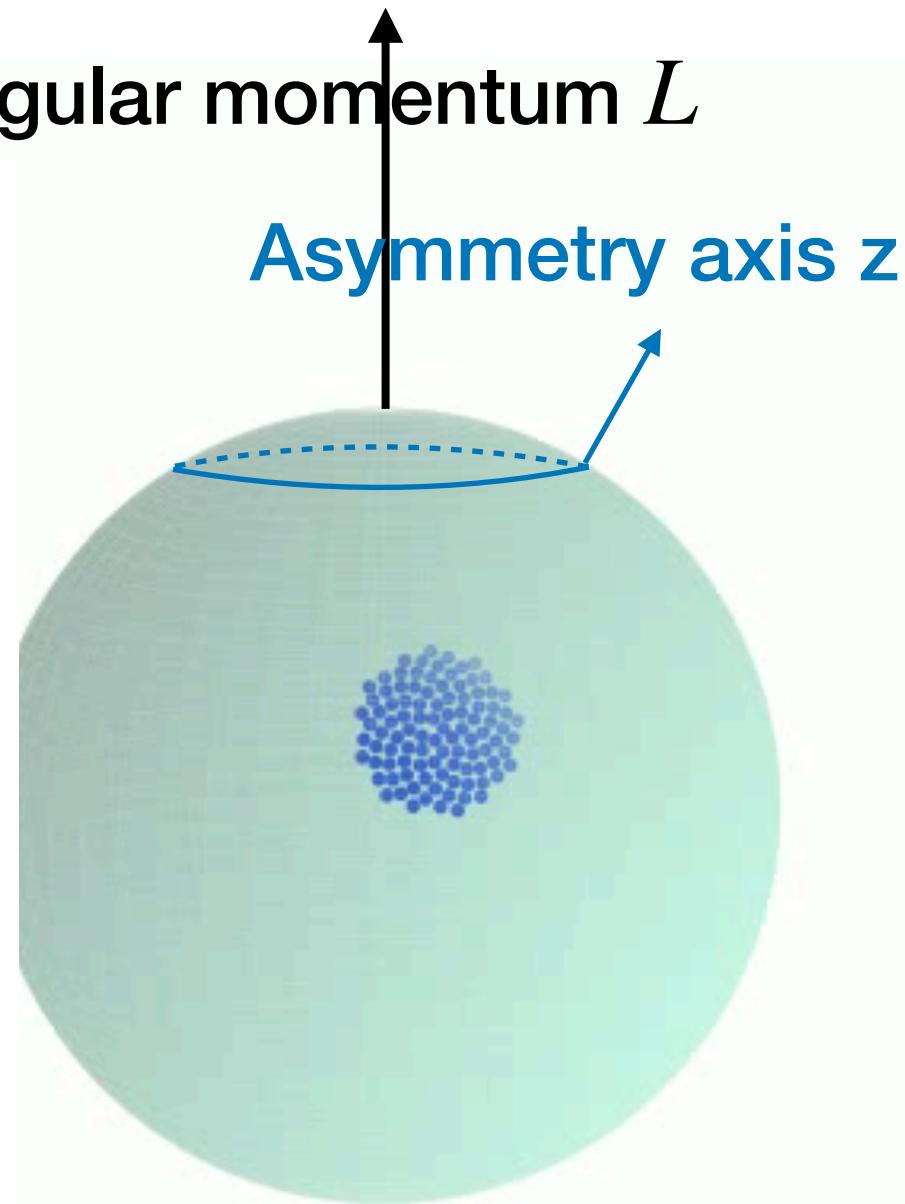
Sam D.



Prolate

Angular momentum L

Asymmetry axis z



Free precession

Search method

Period search

Assume period P

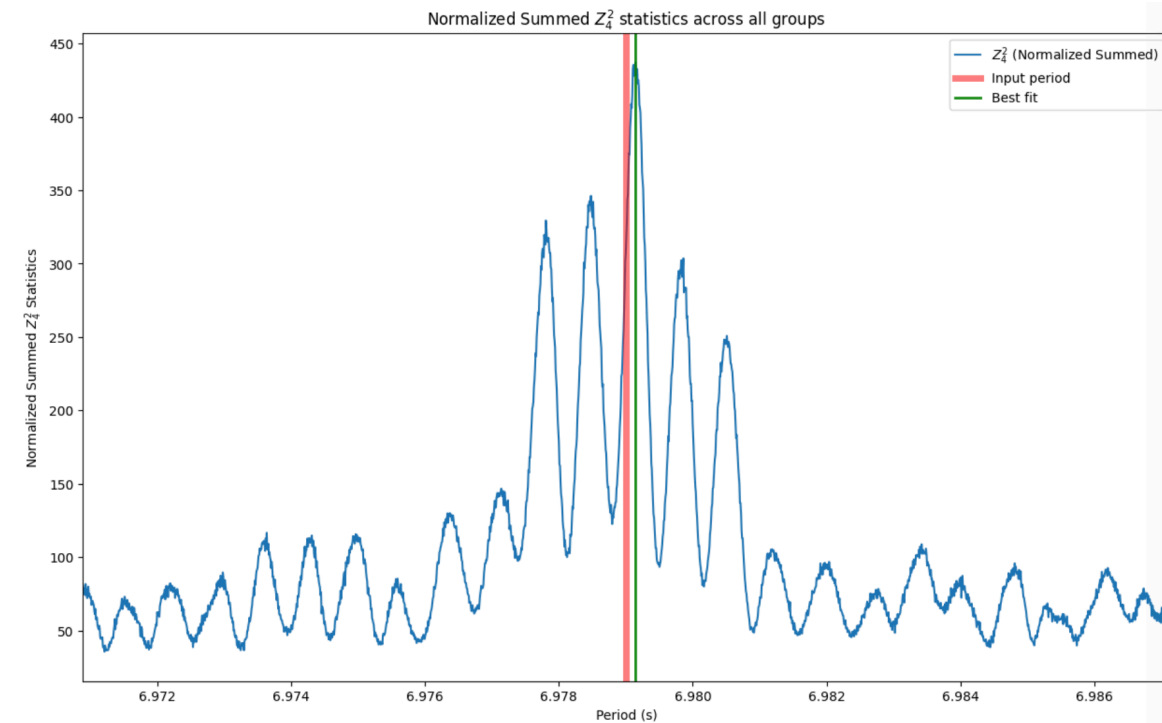
$$t \rightarrow \phi$$

$$Z_n^2 = \frac{2}{N} \sum_{k=1}^n [N + \sum_{l=1}^N \sum_{m=1, m \neq l}^N \cos(k\phi_l - k\phi_m)]$$

Buccheri +83

n: harmonic number

N: total photon

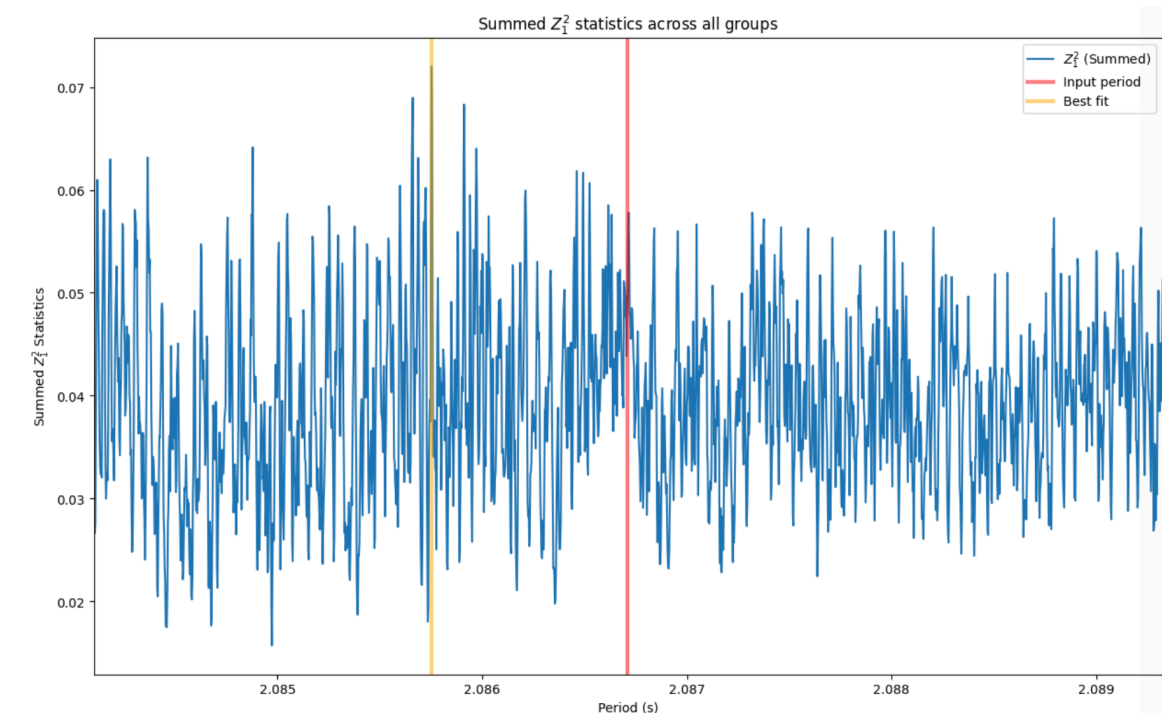


Correction of modulation T

$$t'_n = t_n - A \sin \frac{2\pi t_n}{T} - \psi$$

A: amplitude caused by precession

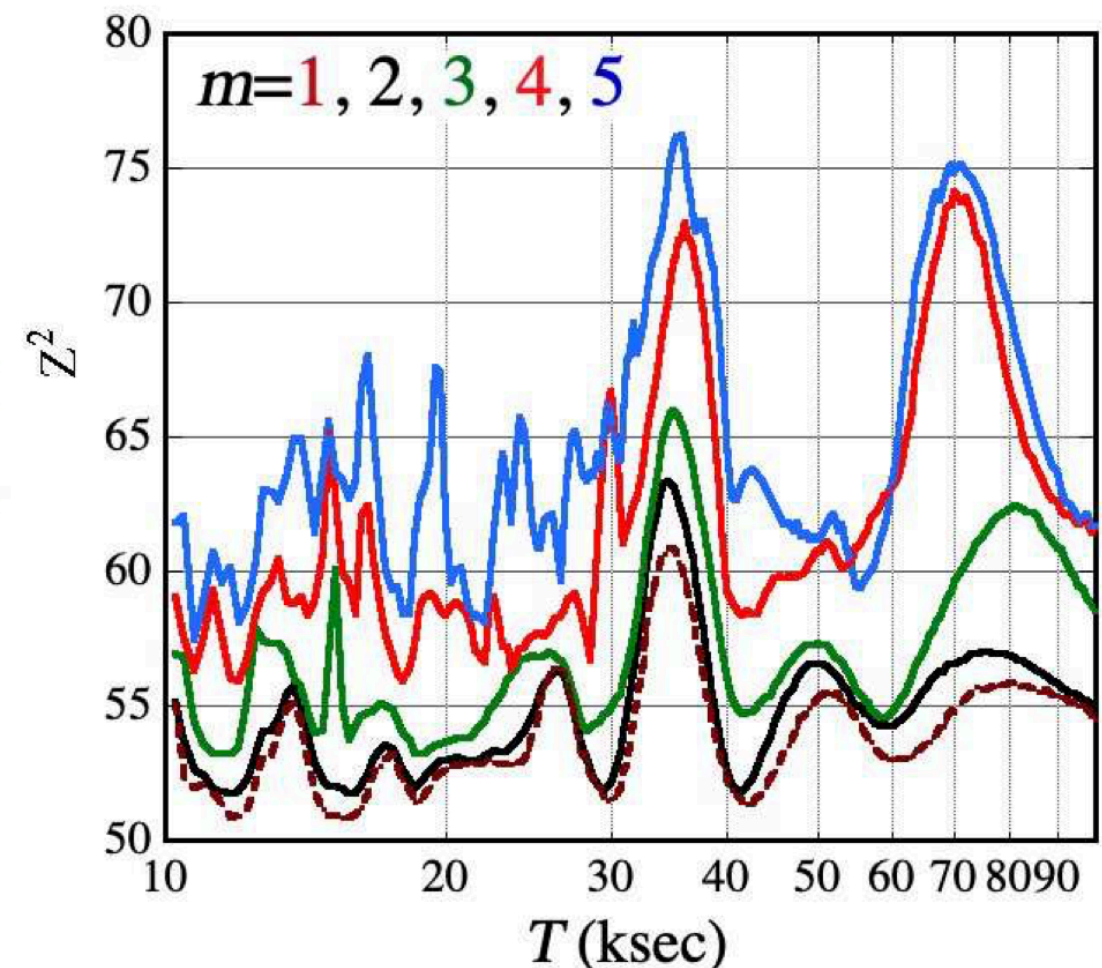
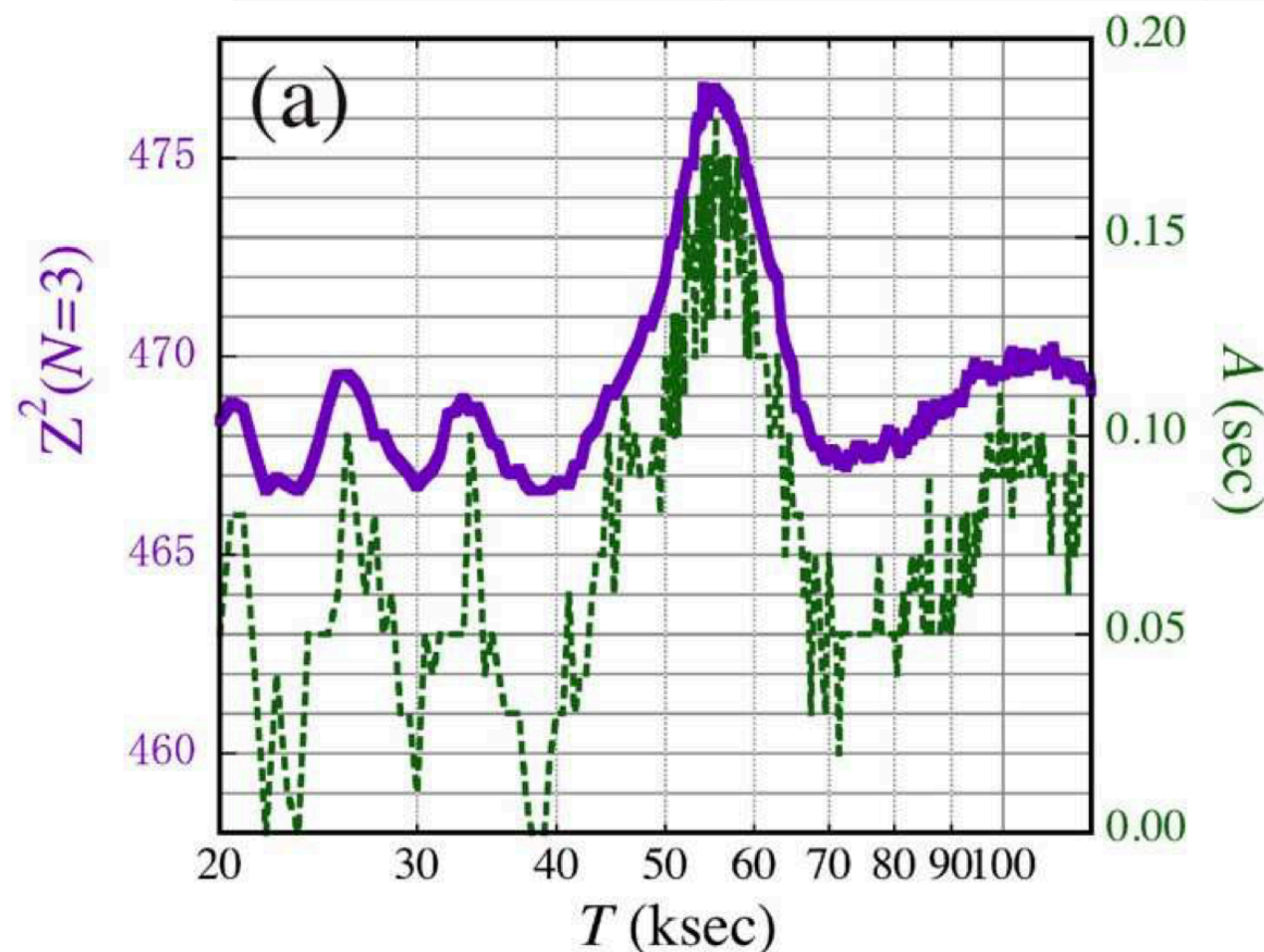
T: modulation period ψ : phase



Previous studies on modulation

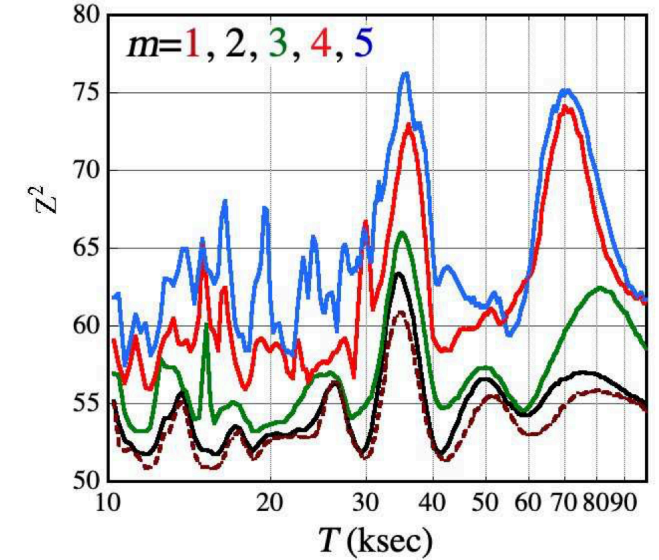
Makishima +14,16,19,21,24

Target	Instrument	P(s)	T(ks)
4U 0142+61	Suzaku, NuSTAR	8.7	55.0
1E 1547.0-5408	Suzaku, NuSTAR	2.1	36.0
SGR 1900+14	Suzaku, NuSTAR	5.2	40.5
SGR 1806-20	ASCA	7.5	16.4

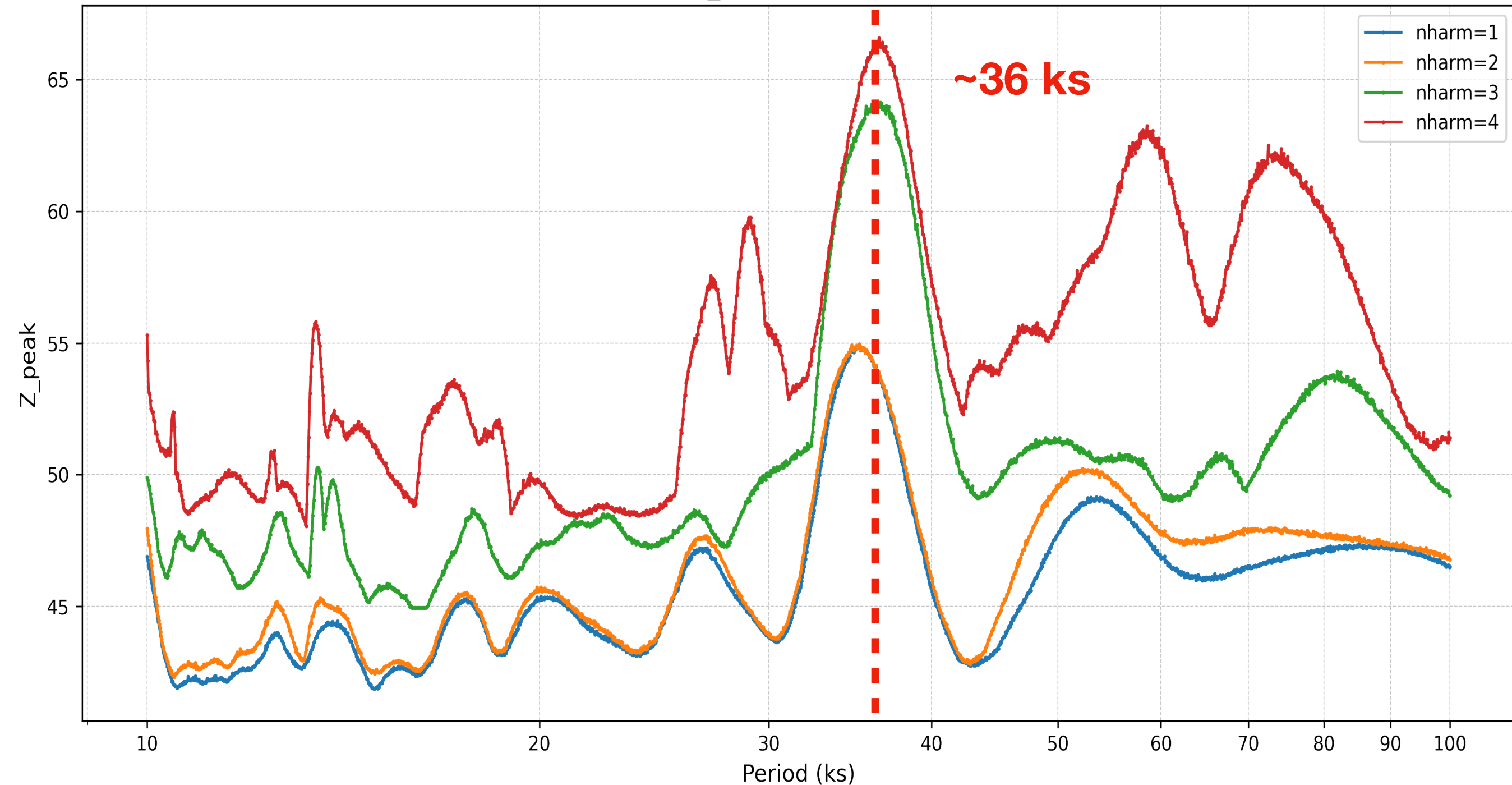


Cross check of 1E1547.0-5408

Same modulation T detected! $T \sim 36$ ks



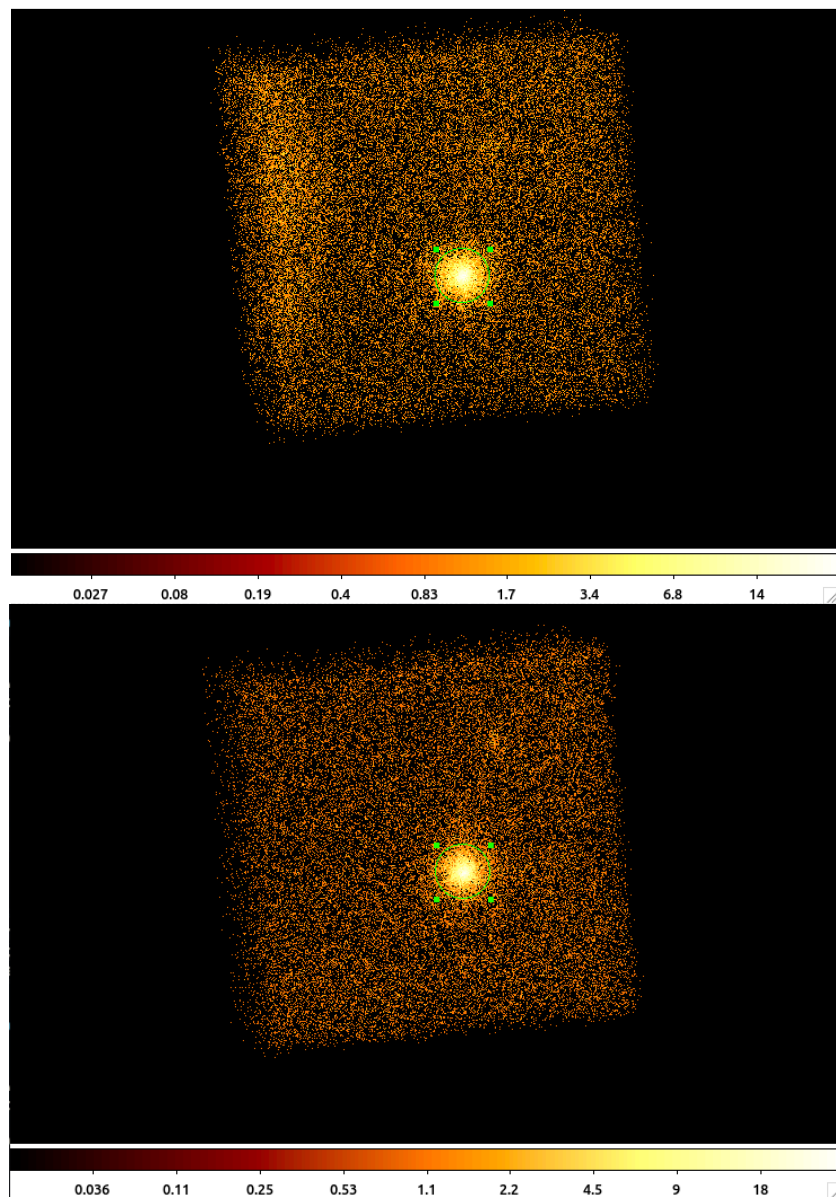
obsID:30101035002, Z_{peak} vs Period (Log Scale), 8-25 keV



AXP 1E2259+586 data feature

NuSTAR: 3-79 keV, broad band X-ray Observatory

obsid: 30001026002



Observation date	
2013/04/24	2013/05/16

Exposure (s)	
36564	87812

Photon counts	
13583	37240

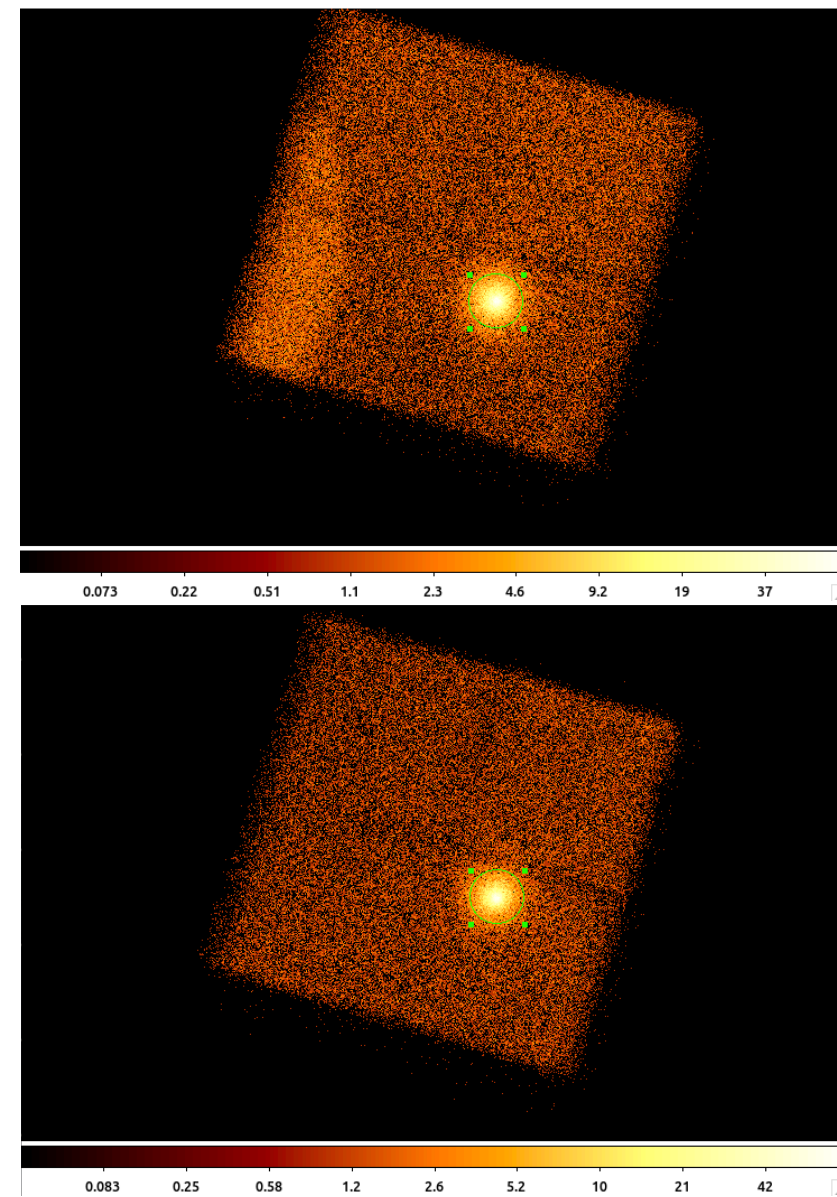
$$P : 6.98 \text{ s}$$

$$\dot{P} : 4.8 \times 10^{-13} \text{ s/s}$$

$$B_{sur} : 5.9 \times 10^{13} \text{ G}$$

$$D : 3.2(2) \text{ kpc}$$

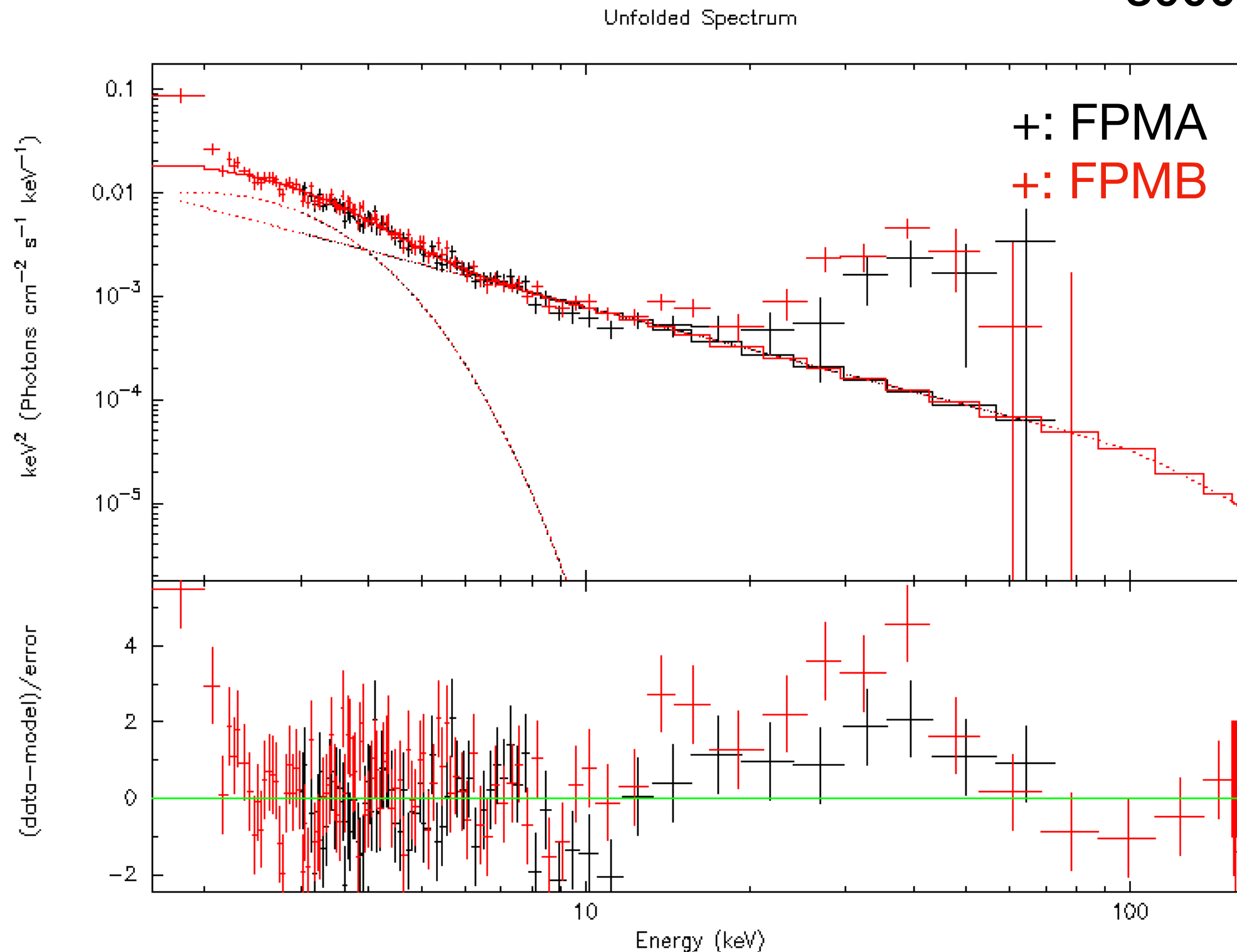
obsid: 30001026007



1E2259+586, spectrum, 3-79 keV, grppha min 50

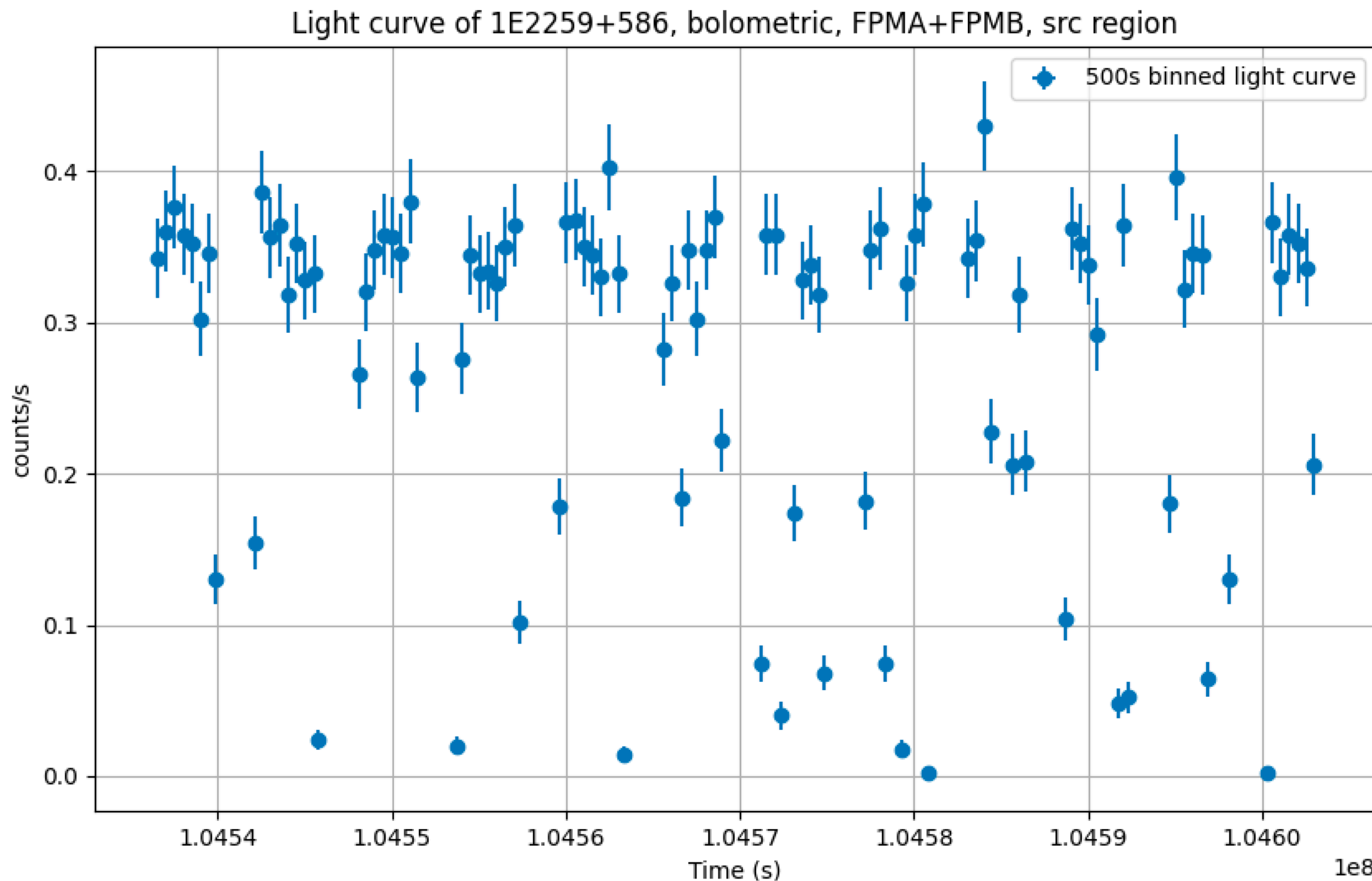
tbabs*(**bb+pl**), 吸収*(黒体+power law)

30001026002



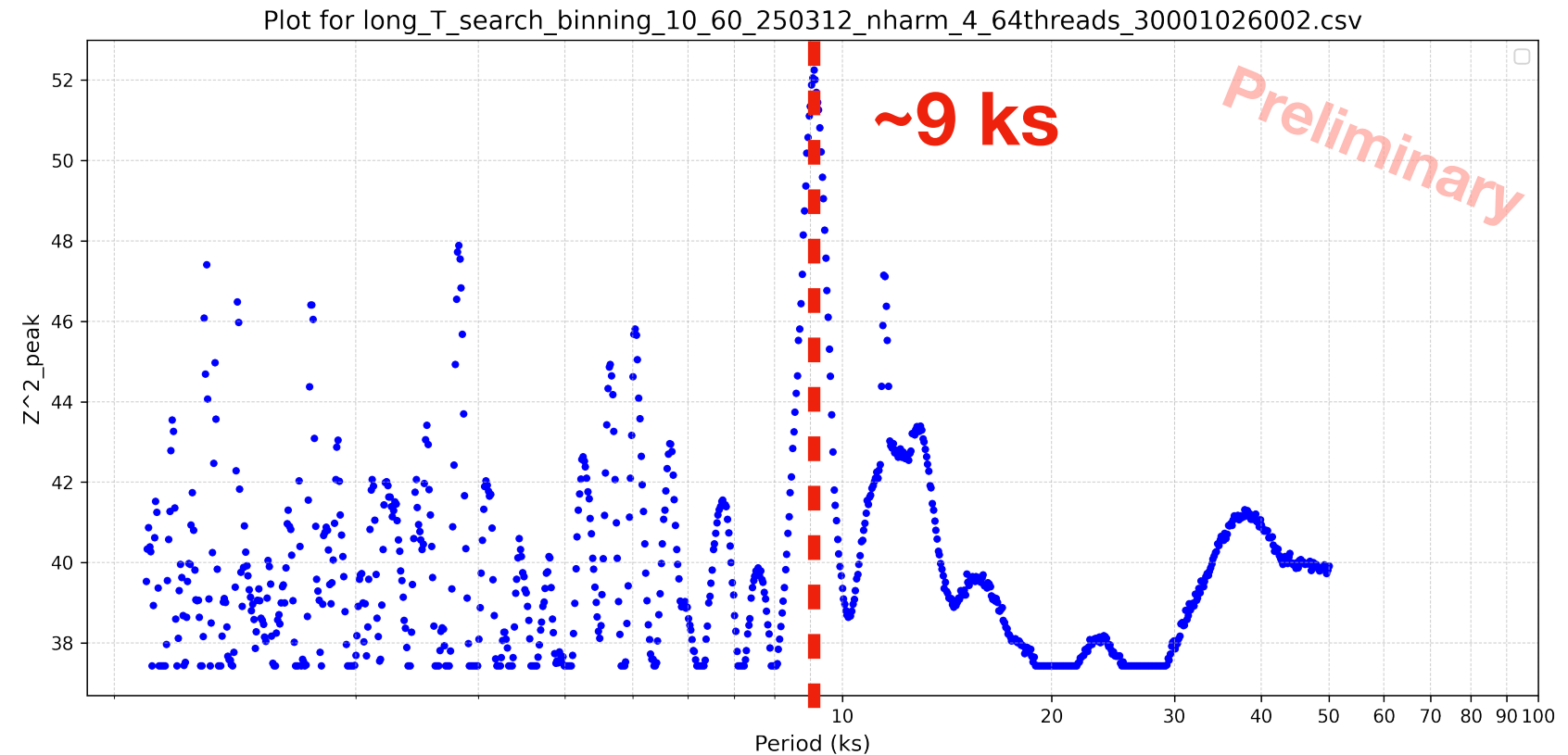
1E2259+586, light curve, 3-79 keV, binning = 500s

30001026002



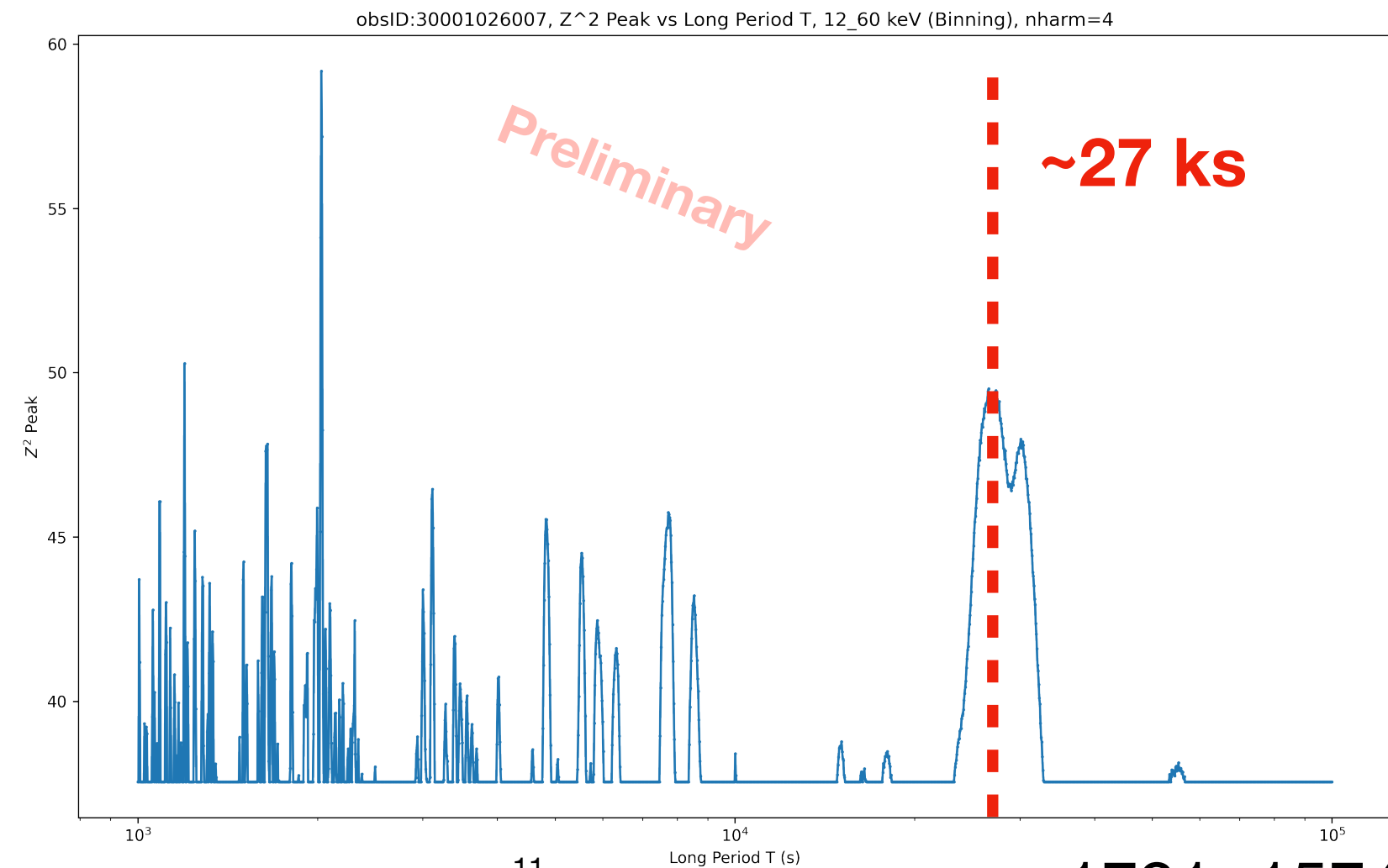
Result

- 30001026002 and 30001026007 gives different result of modulation period T



1067

- Are peaks real or from noise?

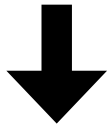


3295

Mock data simulation

Sinusoidal pulse pdf

$$f(\phi) = 1 + a \sin(2\pi\phi)$$



$$t_n = t_0 + P(k_n + \phi_n)$$

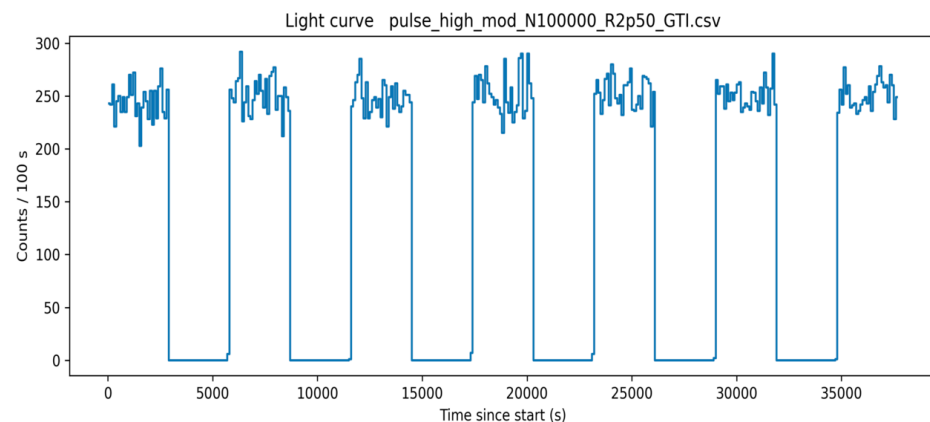
Modulation shift

$$t'_n = t_n - A \sin\left(\frac{2\pi t_n}{T} - \psi\right)$$

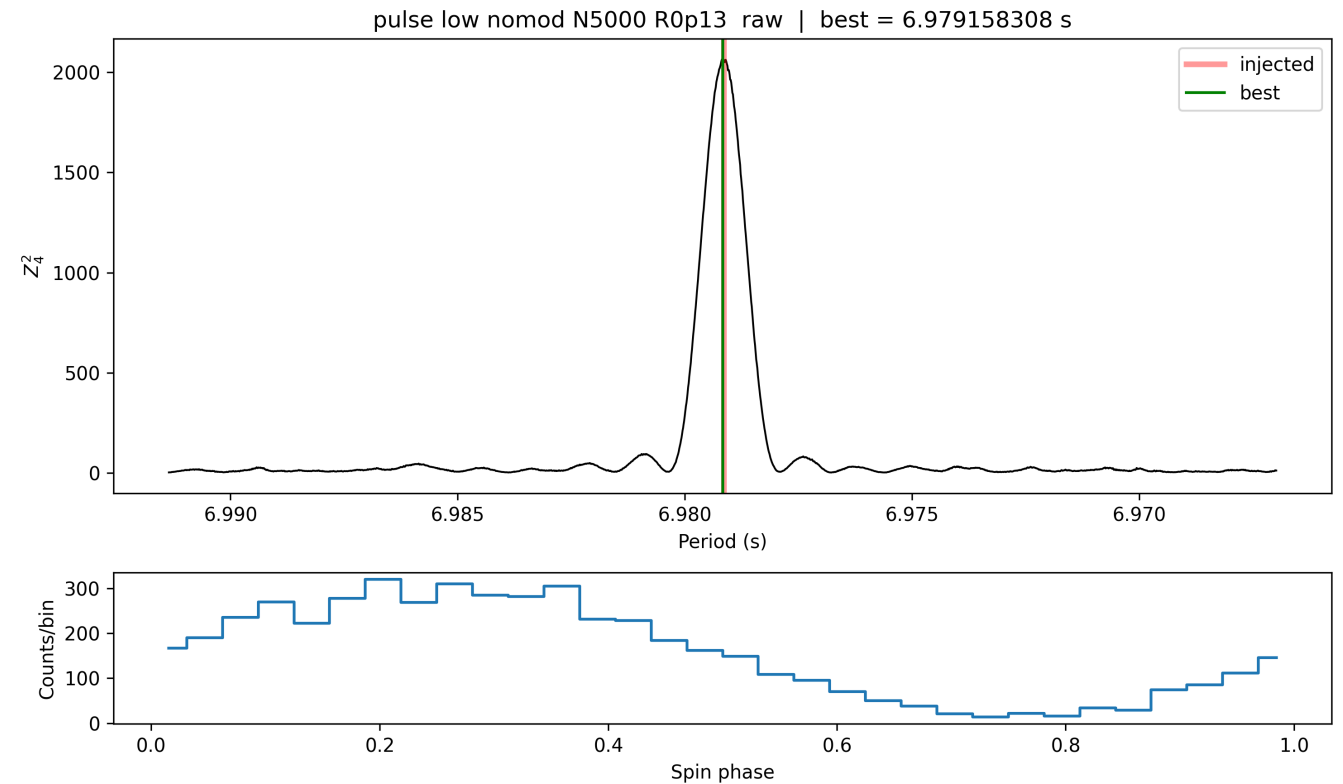
Time interval

$$P_{orbit} \approx 5800 \text{ s}$$

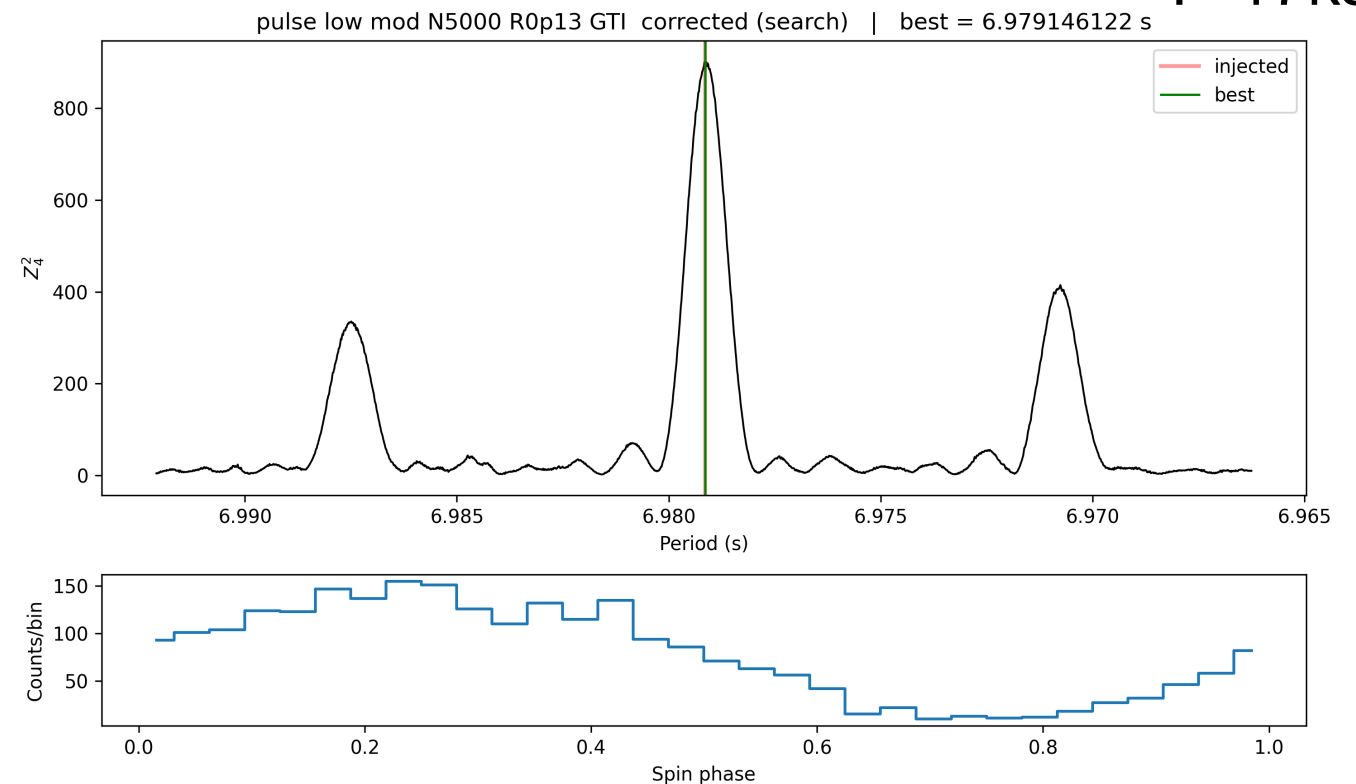
Remove half of the photons



5000 Photons, pure pulse, duration=40ks

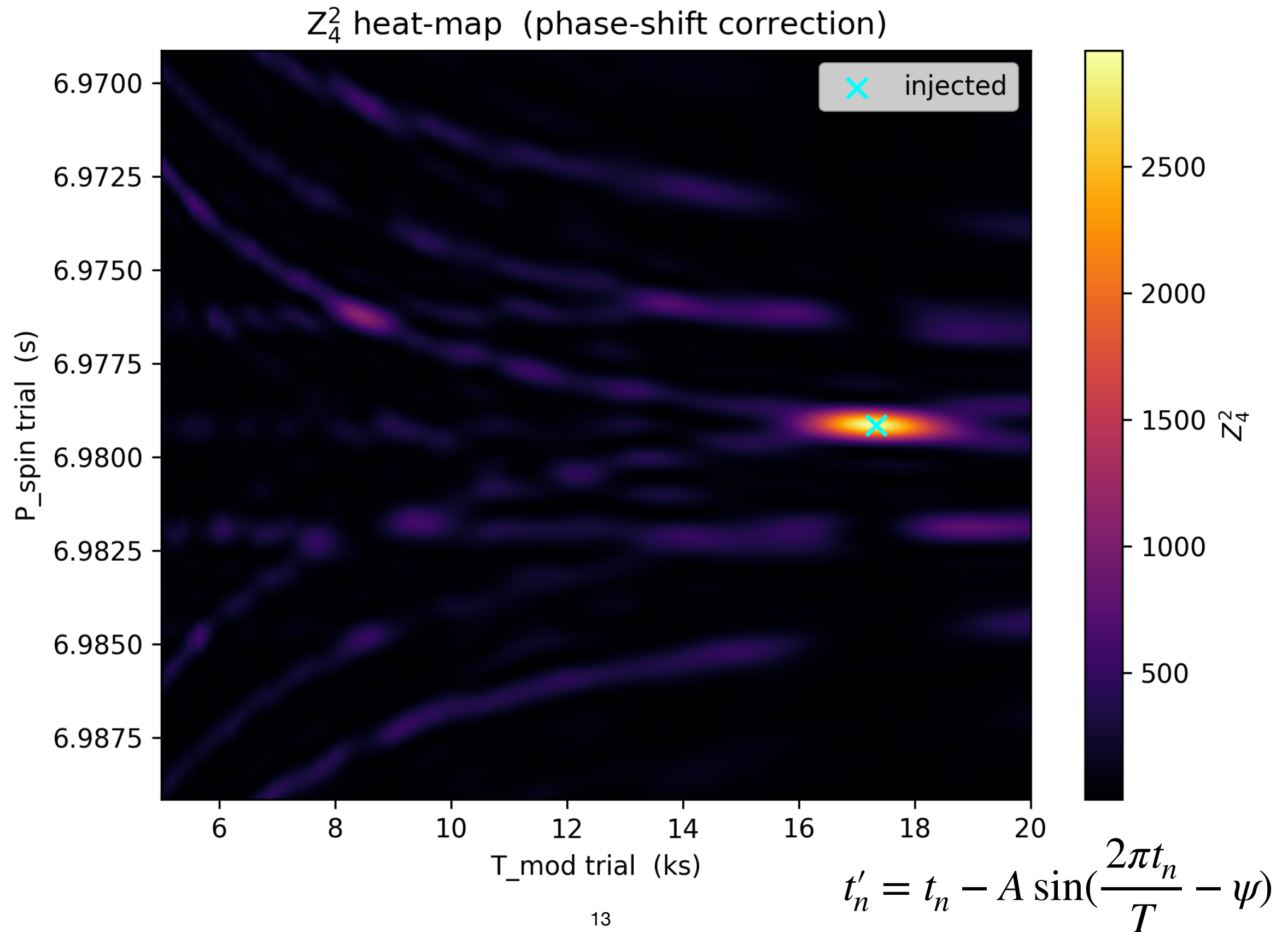


T=17ks



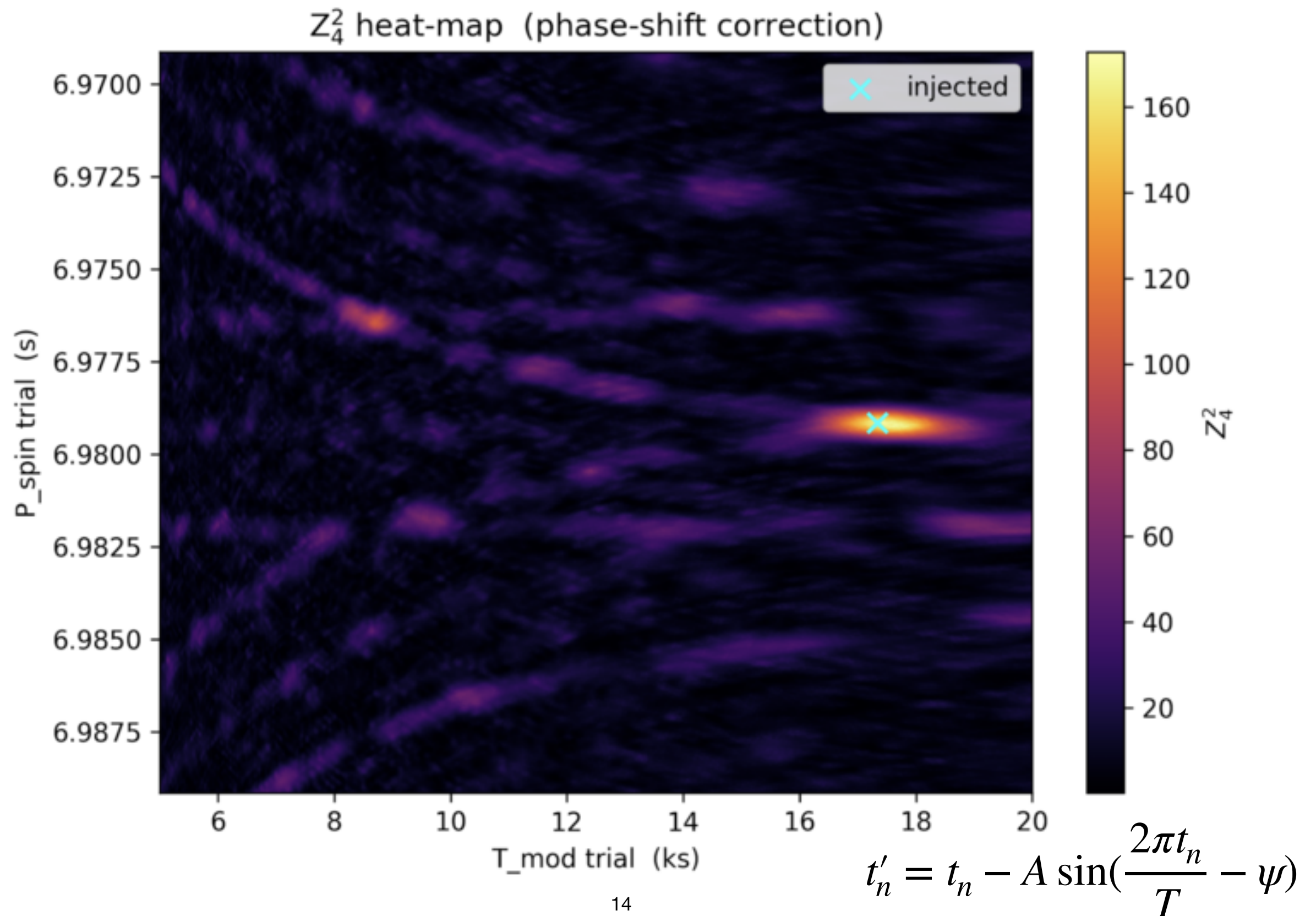
Mock data simulation

Photon counts: 4832



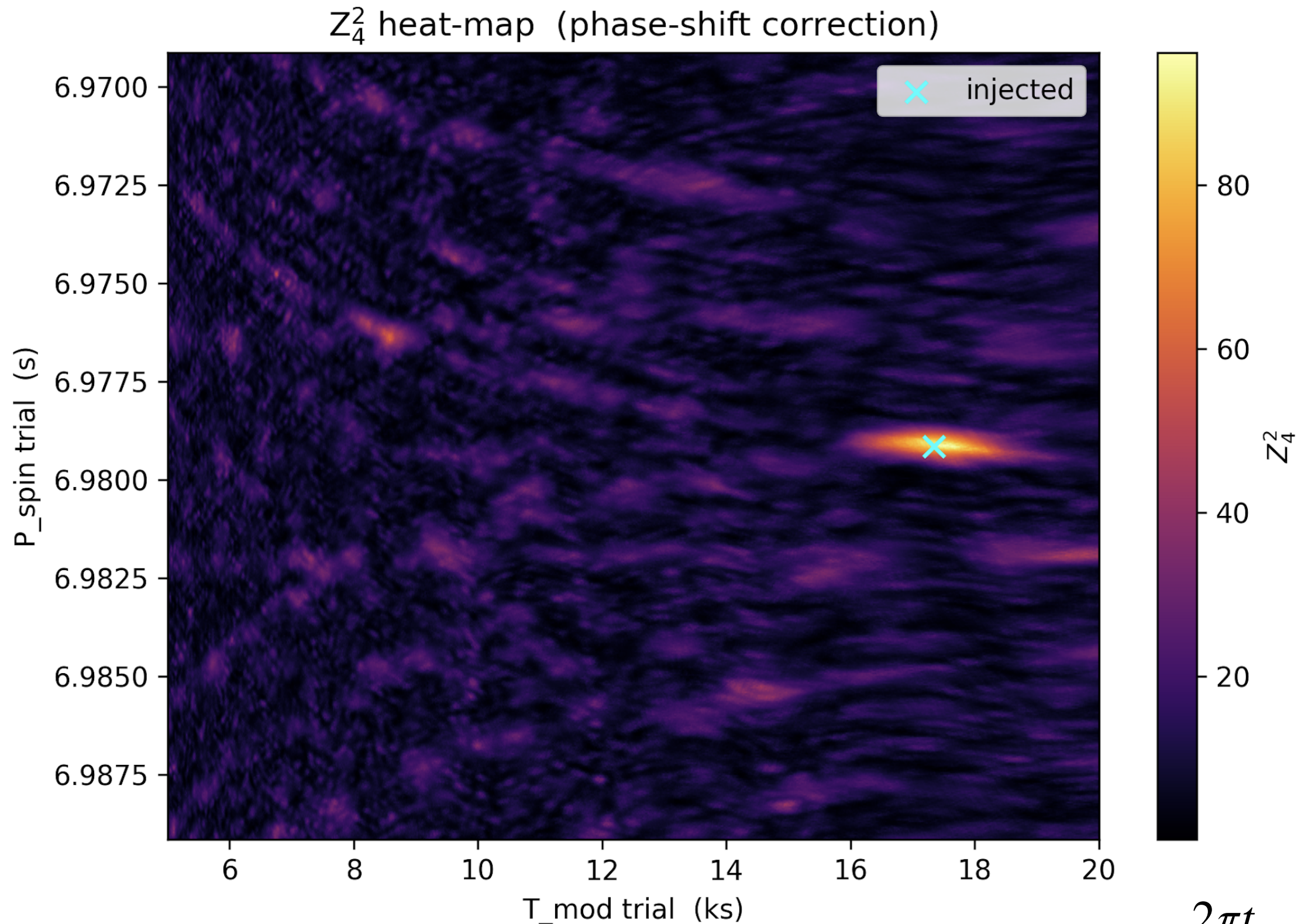
Mock data simulation

Photon counts: 308



Mock data simulation

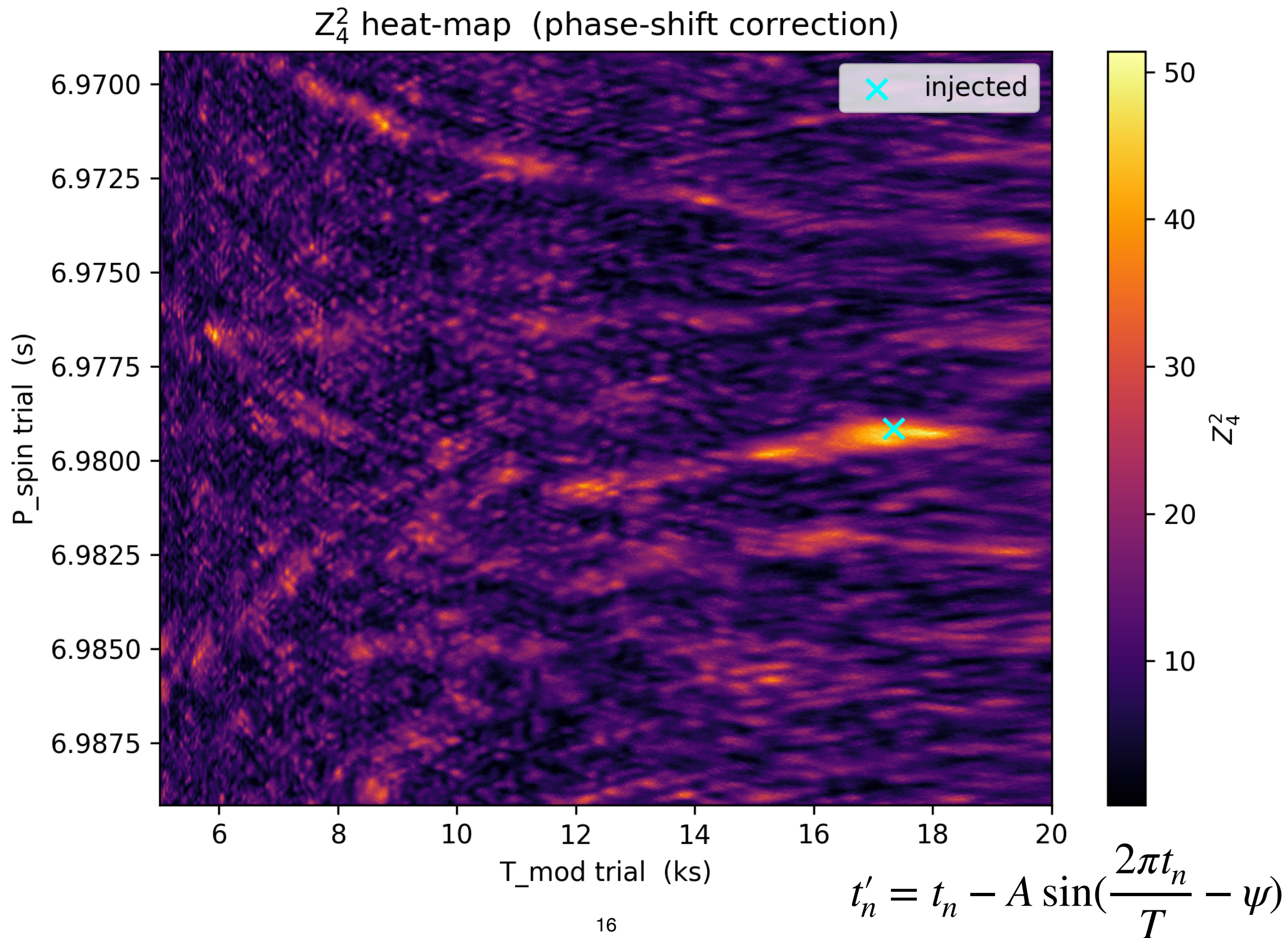
Photon counts: 151



$$t'_n = t_n - A \sin\left(\frac{2\pi t_n}{T} - \psi\right)$$

Mock data simulation

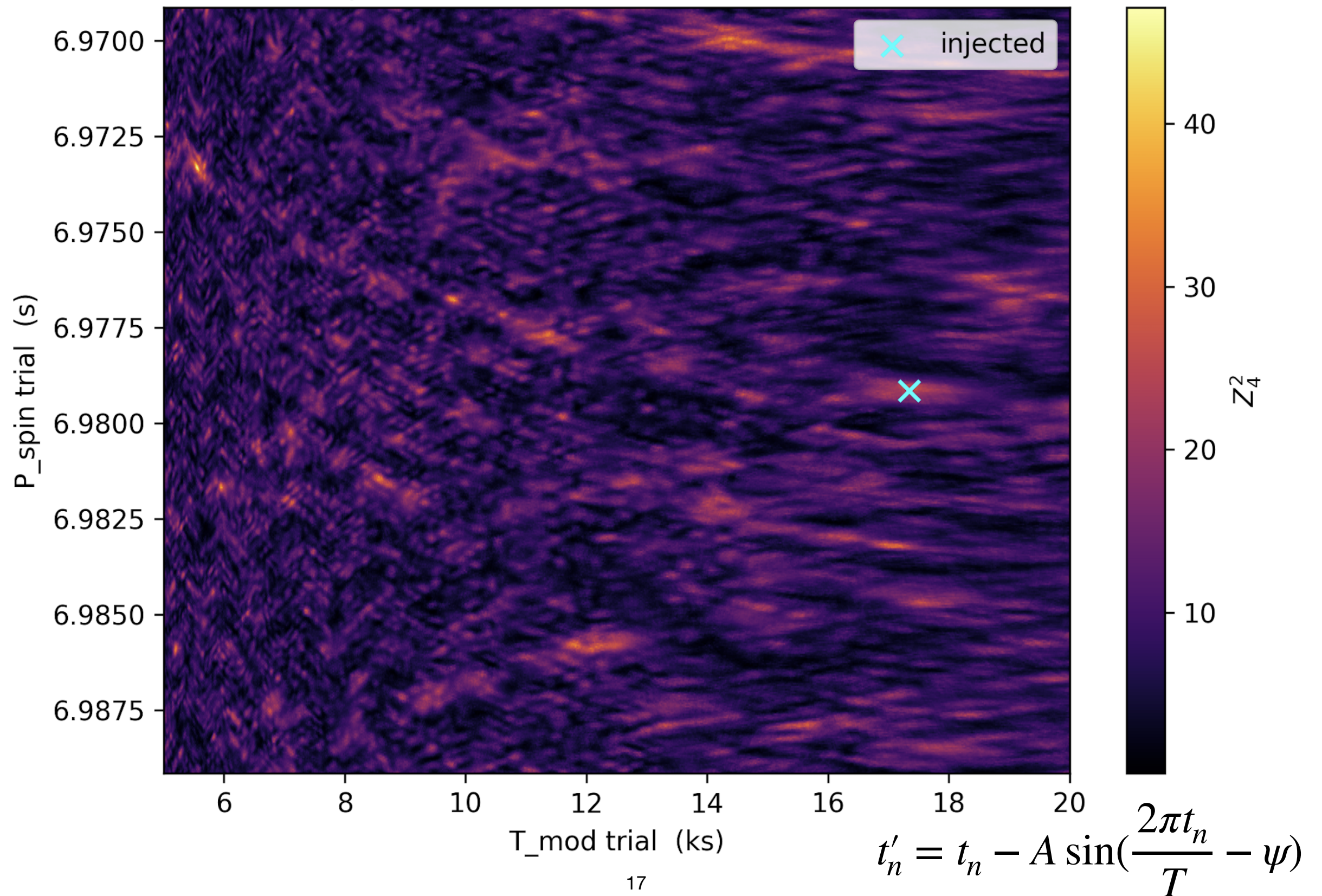
Photon counts: 78



Mock data simulation

Photon counts: 43

Z_4^2 heat-map (phase-shift correction)



Summary

Github: [Magnetar_modulation_mock_analysis](#)

- 1E2259+586 has 2 different possible T_{mod} in 2 observe data which are ~ 9 ks and ~ 27 ks ($\Delta t \approx 1$ month)
- Developing mock data analysis to determine the reliability of modulation analysis
- Going to apply geometric model to fit the observation

